On a Method of Avoiding Collision at Sea.

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I have in the foregoing paper already described a method of finding distances at sea in fog or thick weather. It is desirable to briefly recapitulate here the principle involved. Signals travelling at differing rates are simultaneously sent out from the lighthouse or signal station. Thus there might be a submarine sound along with an aërial; or, again, a wireless signal along with an aërial sound; or, finally, the combination might be the sound in water and the wireless signal.

Such simultaneously emitted signals become relatively displaced as they are propagated outwards. After travelling a distance of one nautical mile a sound in air will lag behind a sound in water by a time interval amounting to about 4·3 seconds. And an aërial sound will lag behind a wireless or a luminous signal as much as 5·5 seconds in the mile. Hence as the lag continues to increase at these rates per mile, the observation of the interval separating the reception of the signals on the ship will enable the navigator to determine his distance from the signal station. It is obvious that similar methods will enable the mariner to tell the distance of another vessel. An error so great as one half second corresponds with an error of only 90 fathoms in the case of the most sensitive combination—that is wireless signal and aërial sound.

The application of this method to the end of avoiding collision at sea involves the means of emitting crisp, and sufficiently loud, sounds in air, which can be timed to coincide in moment of emission with wireless signals, or, in certain cases, with luminous signals. Long-distance wireless signals are not required. A more perfect installation would include the power of emitting and receiving submarine signals.

There can be no serious difficulties in the way of imparting to the signals the quality of simultaneity. Where electric control can be used directly or indirectly the problem involves little more than the provision of suitable clockwork for regulating contacts. Again the degree of skill or intelligence called for in timing the receipt of the signals is not so great as to limit the use of the method to the more highly educated seaman. A very little practice, which can be obtained at any time, will give all the requisite skill in using the stop-watch. With ordinary care to read the successive signals in the same manner, the error in estimating the interval between them will probably be small. This I have already discussed in my former paper. There are, I believe, neither mechanical nor personal difficulties in the way of good determinations of distance between ship and ship. Nor would the necessary additions to the Board of Trade Rules be considerable, as will presently appear.

The means by which the determination of distance may serve to reduce or eliminate the risk of collision I shall now explain. I am fully alive to the fact that to expect of the mariner the solution of complex analytical or geometrical problems, under the conditions of anxiety obtaining on a vessel being navigated in thick fog, would be futile. The following solution of the problem of foretelling whether or no there is risk of collision with another vessel, and if there is such risk indicating the precise time at which the danger is imminent, even under circumstances when the direction of sound in the air cannot be inferred, is so simple that I would hope it may be of use. The diagrammatic nature and repetitional character of the steps required protect it from risk of oversight or mistake.

When two ships provided with the means of determining distance, as described above, become aware of one another's presence in fog—either by the reception of periodically sent out wireless signals or by the usual regulation sound signals—the following procedure would be adopted.

Each ship sends out: (1) a code signal by wireless giving her course; (2) a signal giving her speed; (3) the wireless signal always emitted simultaneously with the aërial sound signal.

These three signals are made in close succession. They are repeated at intervals: (1) and (2) perhaps every 10 or 15 minutes, or when course or speed are altered: (3) at intervals of, say, two minutes.

In this way each ship knows the course and speed of the other ship and on the result of two successive observations of distance the navigator is able to determine the rate of approach or recession of the other vessel. These data are dealt with at the moment by a simple geometrical construction now to be described.

The decision as to whether there will be collision or not turns upon the fact that if the rate of mutual approach of the ships is the maximum for the given conditions of course and speed there will be collision. If they are approaching one another at a rate less than the maximum rate there will not be collision.

The truth of this statement is evident when it is considered that the point of collision (if there is one) is a common point on the line of advance of both vessels: and the speed of each ship is being directed to bring her straight to that point. Hence their mutual distance must be diminishing at the maximum rate for the assigned courses and speeds at every instant. If the ships are not directed towards a common point a certain component of their velocity is always acting to separate them, or, in other words to lessen their rate of approach. Considered when the ships are approaching end on (suppose one is going north and the other is going south) the statement is obviously true; for only when they are advancing in the same line is the rate of approach a maximum, and then only can they collide. Similarly it is obvious for one ship overtaking another on a common course. The general statement perhaps needs more consideration. It will presently be more fully set forth.

In fig. 1 let one ship be going north. This ship we will call A. Her speed is such that she occupies at successive intervals of two minutes the positions

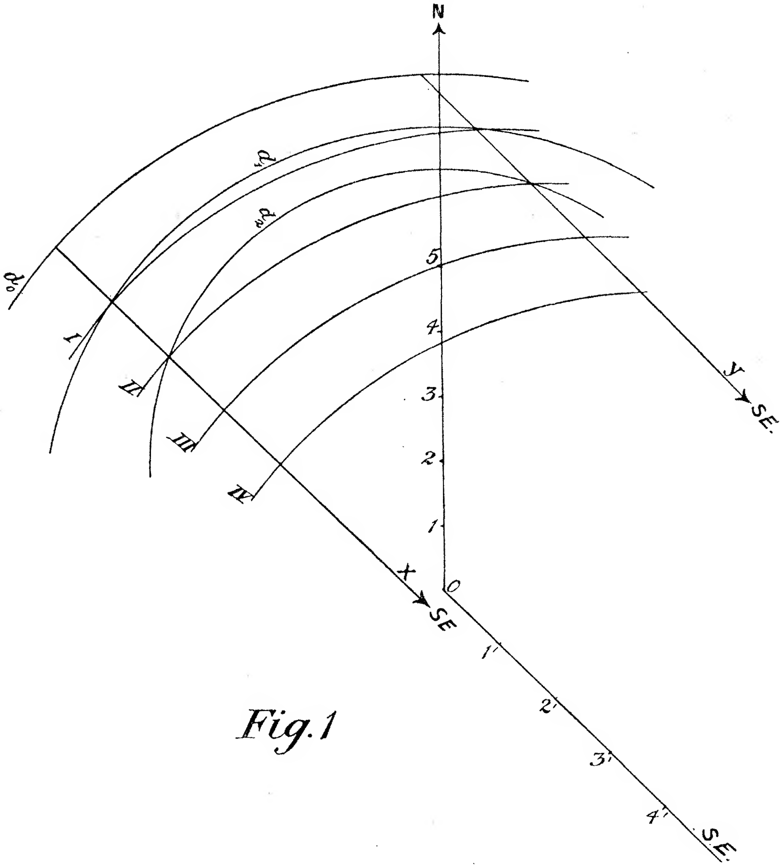

Fig. 1

0, 1, 2, 3, etc. These are, therefore, her positions when receiving the successive signals from another ship we will call B.

When A is at the point O she receives the first signal from B, to the effect that B is holding, say, a south-east course at a speed of n knots per hour. The distance signal shows that B is at a distance of d_0 knots.

The navigator on A strikes a circle with the point O as centre and with the radius d_0 taken to the same scale as he used in setting out the points 1, 2, 3, etc.

As no reliance is supposed to be placed on the fancied direction of sounds from B, nothing more is known on A beyond the fact that B is somewhere upon the circle having the radius d_0, and marked d_0 upon the diagram.

Laying off from the point O, a line bearing south-east, the navigating officer on A lays off from O along this line, and still to the common scale, a few points giving the displacement of B on her course every two minutes. With these points successively as centres, he strikes the circles I, II, III, etc., to the common radius d_0. He knows that B will be transferred from one of these circles to the next in the course of successive intervals of two minutes. This is true, no matter where she is placed on the first described circle. He now awaits the second signal from B, giving her new distance.

The new distance is d_1 knots. If d_1 is greater than d_0, the vessel B is evidently receding from A, and must occupy some place on the south-east half of the circle I. To prove this it is only necessary to take the distance d_1 in the compass and with the new position of A as centre, that is to say, point 1 on the course of A, to cut the circle I. The two points of intersection will lie on the south-east half of circle I. One or other of these points of intersection must be the position of B. Hence, when d_1 is found to be greater than d_0, the observations need not be carried further.

If d_1 is less than d_0, B is approaching A. In this case a circle struck with d_1 as radius (always to the common scale), and the new position of A as centre (*i.e.* point 1), in general intersects circle I in two points, These points are in the north-west half of circle I, and in one or other of them B must be located at the instant. For these points are the only points common to circle d_0 and circle I, and we know she is on both circles.

The arc d_1, in place of intersecting circle I, might touch it only, *i.e.* be tangent to it. In this case we get but one point on circle I. This unique point is the position of the ship B.

If the arc d_1 intersects circle I there is no risk of collision. If it touches it only there will be collision.

In stating the result in this definite manner, we assume quite accurate conditions and measurements. Some error there must be, however, and, from the practical point of view, it is only correct to affirm that, if the circle to the radius d_1 clearly cuts the circle I at two points so that the result is beyond the limits of error, there is no risk of collision, while, if it touches it, or within the limits of error might touch it, there is risk of collision.

In the case where there is intersection, and a line bearing south-east is drawn through each point of intersection, the ship B is advancing along one or other of these lines, marked X and Y on the diagram (fig. 1). The mariner cannot distinguish which of these lines she is on, either from this or from succeeding observations. He can only do so by altering his course and testing the results as to distance. But this is of no importance. In general, if he knows he is clear of the other ship, it is all he cares about.

Considering the result that there are two possible lines of advance for B when d_1 gives us two points on circle I, we recognise that there cannot be two lines of advance leading B into collision with A, that is to say, leading to one particular point on the line of advance of A. For the two lines holding the same course are parallel, and hence cannot meet at a point. This is proof of the theorem that if the arc struck from 1 to to the radius d_1 meets circle I on two points there cannot be collision.

While it is true that if collision is not going to occur, there are two possible lines of advance for B, it is also true that if collision is going to occur there is but one line upon which B can be advancing. This unique line of advance is determined when the arc d_1 is tangent to circle I (fig. 2). For we have only now to draw a line bearing south-east (the given course of B) through the point of contact of arc and circle. Where this line cuts the successive circles II, III, etc., the ship B will find herself in the succeeding intervals of three minutes. If we follow the advance of B upon the diagram in this way, and compare the successive positions of ship A, we will find that both vessels meet at a common point of advance. In order to fix with more precision the position of this line of collision, join the points 1 and 1′, and produce to intersect circle I. This gives the point of tangency when the arc d_1 touches the circle. It is well to check the position of the collision line by also joining 2 and 2′, and 3 and 3′, and intersecting the circles II and III with the lines so found.

Before proceeding further we may revert to our original statement that the line of collision may be defined as that of the maximum rate of approximation of A and B. Our construction is based upon that fact. For when d_1 gives a tangent arc it is evidently the least distance which conforms to the condition that the second position of B is on circle I. Hence the value of d_1 is the least possible, and it follows that the rate of approach of B to A has been the greatest consistent with the conditions of course and speed. Similarly we see that if d_1 intersects circle 1 a greater value of d_1 than the minimum is involved and therefore the rate of approach of B to A is not the greatest; that is, it is not so great as when there is a line leading to collision.

Having ascertained that there is risk of collision with B, the navigator can, if circumstances permit, continue to observe the approach of B upon the diagram and thus confirm the first inference. If the successive arcs d_2, d_3, continue to indicate risk of collision, according to the rules of the road the vessel B keeps out of the way of A.

On the question of the usefulness of this method we have two considerations before us: the reliability and definiteness of its indications and the degree of facility with which it can be put in execution.

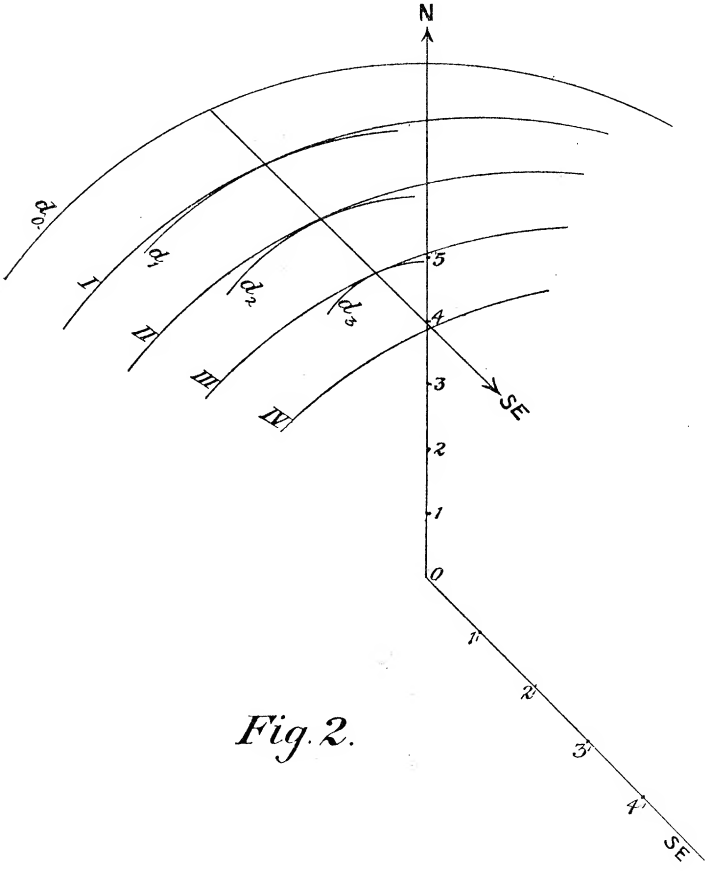

Fig. 2.

Regarding the first point, the method proposed claims to tell the mariner (1) whether there is risk of collision or not, and (2) the probable moment of danger if collision is threatened. These claims are undoubtedly justified, although certainty in the prediction of collision is unattainable, for the simple reason that perfectly accurate estimates of speeds, courses and distances are unattainable. But *risk* of collision is foretold. In fig. 3 possible effects of error are shown. We here assume that large errors of distance, of the same sign, have affected the observations throughout. Tangent arcs have become intersecting arcs. The distinction between this and the case of fig. 1 is obvious. For error of observation is not cumulative. Each determination of distance is an independent observation. Hence the successive arcs, d_1, d_2, etc., are separated by similar radial elevations above the arcs they intersect. Such a feature at once warns the mariner that the intersection is not real. Under conditions of safety each observation shows an increasing departure from the conditions of danger, the separation of the arcs getting more and more pronounced. The diagram, in fact, faithfully interprets the external facts, for, of course, lag in the approach of the ships behind that of maximum rate of approach constantly adds up, the evidence for safety becoming more apparent in successive observations.

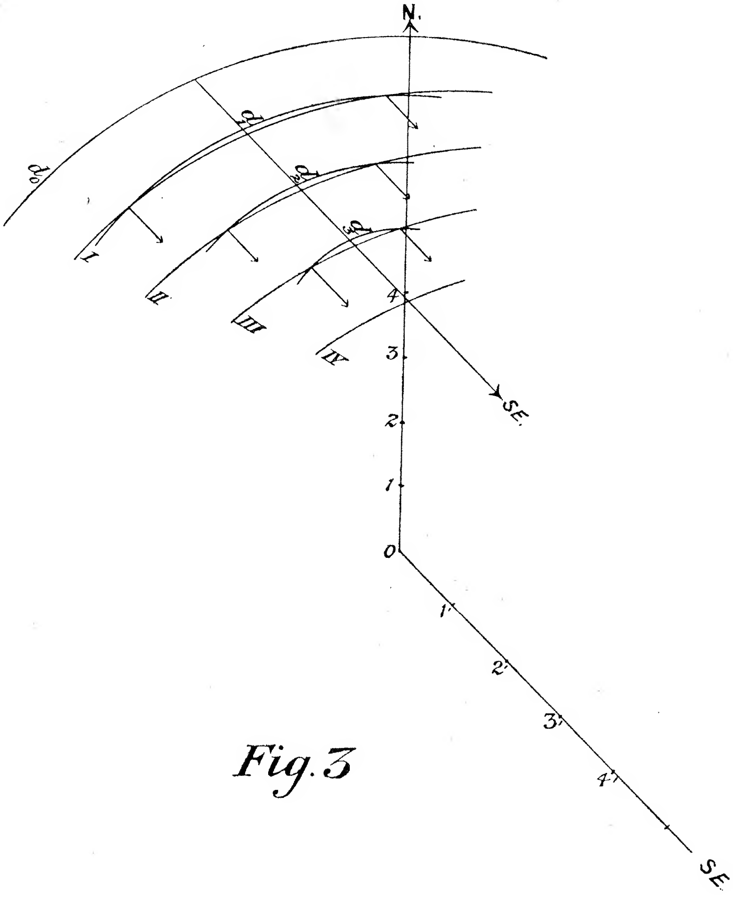

Fig. 3

Hence the method tells the mariner whether there is risk of collision or not.

It also tells him the moment of danger. This is obvious. For the given courses and speeds the point of collision is fixed. Of course, currents and tidal drift might affect the ships differently. Or, again, speeds or courses might vary. It can only be answered that some latitude must be allowed for these things. It may be noted that error introduced into position of the circles I, II, III, etc., due to these causes may be checked at intervals, if time permits, by treating any of the distance determinations as originating a succession of circles of position. If the ship B was a long way off when the first signal was received precision would be gained by this procedure. It is, of course, quite simple. We start a new diagram, say, with d_5 and with the nearest coinciding statement of B as to her course and speed. The construction already described is then repeated.

On the second point, the facility with which the observations are carried out, it must be remembered that all the arithmetical work of determining the distances to be scaled off on the diagram can be eliminated by the use of tables. Quite brief tables would suffice. If B signals that her speed is 12 knots the navigator on A reads at once from his tables what this amounts to in three minutes, or whatever other interval exists between the signals. His scale is, say, 1 knot to the inch. The tabulated number is taken up off a scale of inches divided to tenths. In laying off bearings time is saved by using paper divided to compass points around a central point. He lays the course of his own ship through this point. The bearing of the other ship being given, he at once plots it. The rest consists in describing a few circles and joining a few points. The practical seaman must judge for himself how far this procedure is repaid by the security gained.